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THE POWERED BALLOON SYSTEM

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13. ABSTRACT

The concept, present status and basic problems involved in developing a powered station-keeping balloon with moderate payload capability (approx. 200 pounds) are outlined. The POBAL balloon will float in the seasonal minimum wind fields (60,000—90,000 feet). By supplying enough thrust to overcome the wind-drag forces, the balloon will be kept hovering above a designated location for a duration limited by its fuel supply. The feasibility, choice of balloon design, predicted durations for candidate propulsion methods and other pertinent considerations are discussed. A demonstration flight system using available system components is described. The eventual POBAL capability is contrasted with that of drones and several immediate applications for an operational POBAL system are described.

KEYWORDS: Powered balloon, Powered sources, Propellers

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7. The Powered Balloon System

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7-1. INTRODUCTION

A number of organizations within the Air Force and agencies outside the Air Force such as NASA, the Department of Interior and the Department of Agriculture have expressed an interest in having the capability to suspend a payload over selected points on the ground for long periods of time. A. O. Korn of Air Force Cambridge Research Laboratories (AFCRL) developed the concept of a powered balloon to fulfill this requirement. AFCRL has studied (both in-house and contractually) the feasibility of providing a propulsive force on an unmanned, free balloon to accomplish a high-altitude hovering or loitering mission. These studies show that such a system is feasible at altitudes near 60,000 feet over a number of areas at selected times of the year.

The entire concept of powering a free balloon is dependent upon what we call the "minimum wind field." A number of investigations in recent years have been devoted to the phenomena of maximum winds in the atmosphere, especially those related to jetstream activity. Minimum and zero wind fields have received less attention, apparently because they are of little operational importance in the performance of most aerospace vehicles. Minimum wind fields are, however,

extremely pertinent to high-altitude free balloon applications, whenever it is desirable to obtain maximum flight duration with minimum horizontal movement from a fixed geographical location. Figure 7-1 shows a simplified pattern of the winds

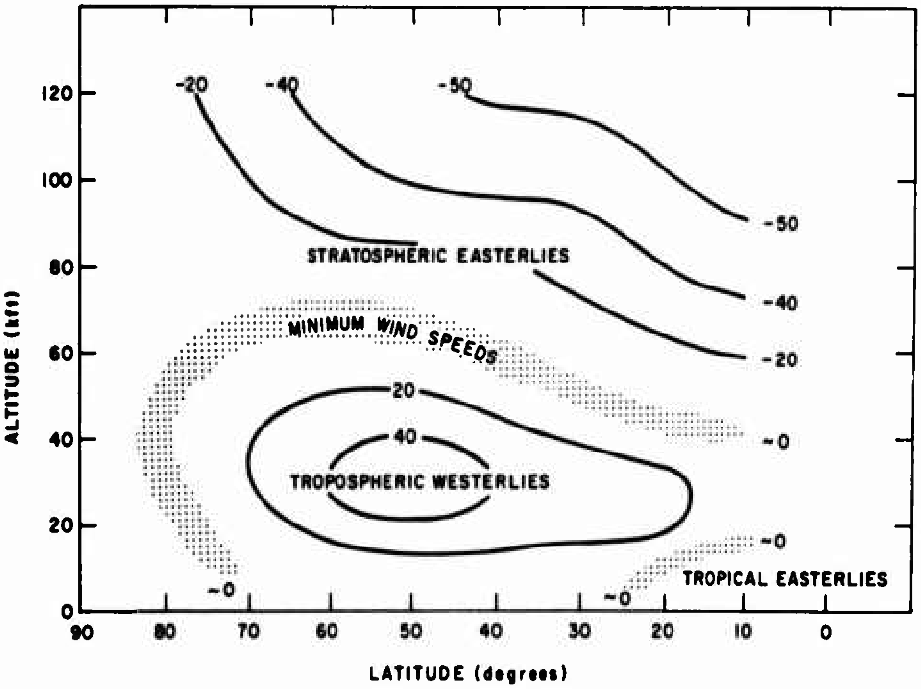

Figure 7-1. Simplified Pattern of the Winds

which cause this phenomenon. Strong westerly winds below strong easterly winds result in a transitional area where the winds are minimum (Figure 7-1). Within this layer there are levels where the winds are essentially zero. Details for the useful application of this phenomenon are explained later.

7-2 HISTORY

For several years the Aerospace Instrumentation Laboratory has been flying unpowered balloons in this minimum wind layer to study the structure of the minimum wind fields and to see if it is possible to keep a flight system over a point on

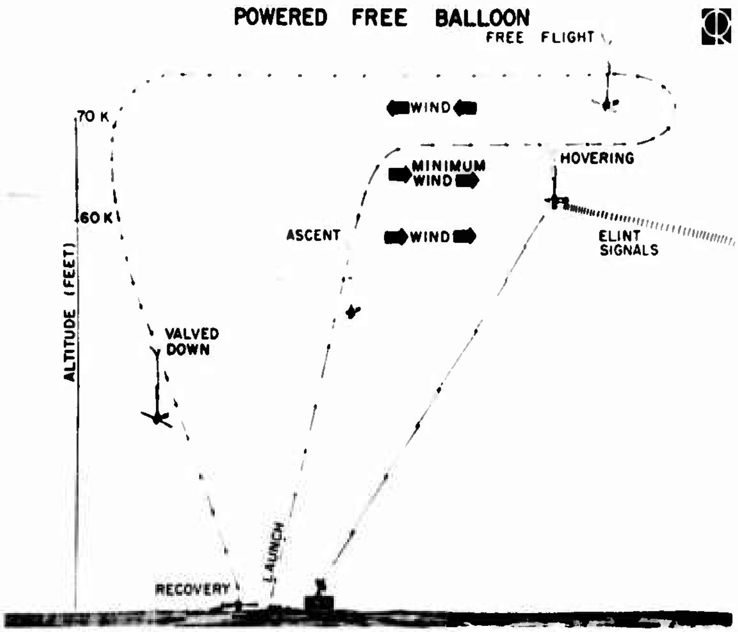

Figure 7-3. Powered Free Balloon Schematic

into the wind by radio control, and stationkeeping is accomplished. After accomplishment of the mission, the payload is recovered.

As a result of this work, a contract was awarded to Goodyear Aerospace Corporation to study the feasibility of supplying just enough thrust to cover all the wind drag on a pressurized balloon and to perform a parametric study to design an economical system for a flight demonstration. A system was designed for demonstration purposes that uses conventional free balloons and existing hardware and launch equipment. This program was funded by the AFCRL Laboratory Directors' Fund. The demonstration is designed to carry a useful payload of 200 pounds to an altitude of 60,000 feet for 24 hours. It has a powered flight duration of 12 hours (50 percent duty cycle) at a speed of 15 knots and floats without power the rest of the time. Figure 7-4 shows the gondola during testing at Akron. The propeller is 36 feet in diameter, and the gondola weighs 3500 pounds. The rudder is 8 feet 9 inches high and 2 feet 6 inches wide.

The system was flight tested at Holloman AFB, New Mexico on 16 September 1972. After three hours of powered flight, the rudder separated from the payload, and the flight was terminated. In the three hours of powered flight the concept was proven. We were able to move the balloon against the wind. The cause of failure

the ground for extended durations without propulsion. These tests have been encouraging in that we have been able to keep a balloon within a 100-mile radius for up to 100 hours (see Figure 7-2). While the balloon is flying, rawinsonde data are used to find a desired wind region. By ballasting or valving we can use the winds to stationkeep.

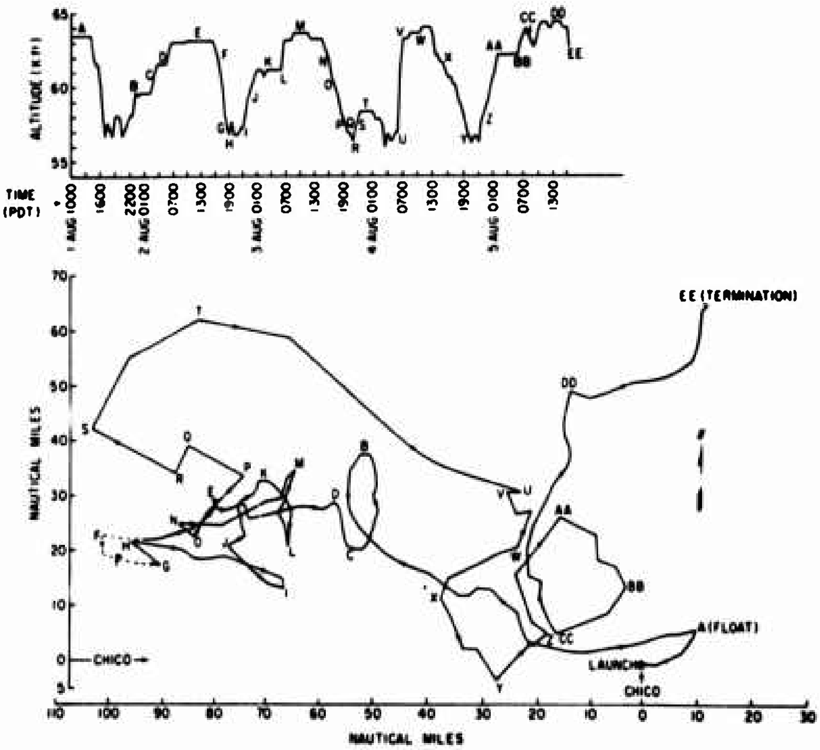

Figure 7-2. Hovering Balloon Flight Track

The concept is shown pictorially in Figure 7-3. The flight system (with its payload attached) is launched in the conventional manner. It ascends to the minimum wind layer unpowered. Upon reaching the min-wind field, the motor is turned

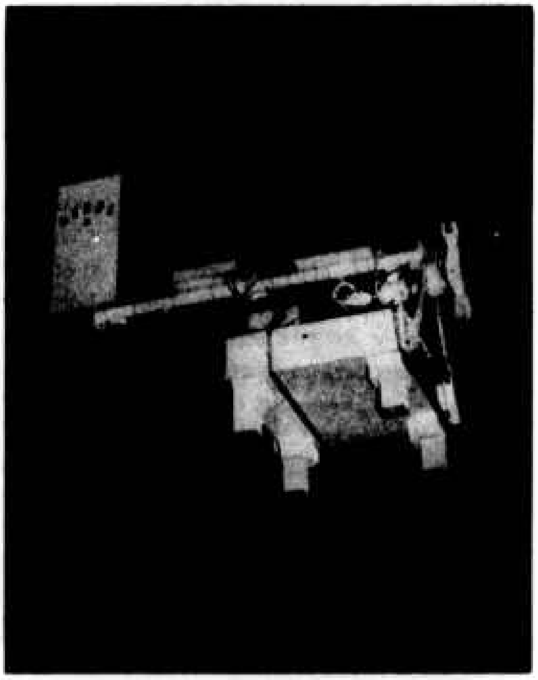

Figure 7-4. Powered Balloon Gondola

is being investigated and believed to be fatigue failure in a 2-inch diameter tube. This is a mechanical problem and not a concept flaw. Current plans call for a reflight in November of this year.

7-3. COMPARISON WITH DRONES

Because the powered balloon, hereafter known as POBAL, is, after all, an unmanned remotely controlled atmospheric vehicle, its performance must inevitably be compared with the capabilities of drone aircraft. Even a generalized comparison, however, is complicated by the need to place the latest experimental drones – which have remarkably improved endurance and altitude – in a category apart from the other fixed-wing unmanned aircraft.

In altitude, for example, most drones are limited to ceilings well below 60,000 feet; but the newest drones fly above 60,000 feet in the same atmospheric regions as POBAL.

Payloads in the range of 200 pounds are typical of both POBAL and drones. There is at least one drone aircraft that can carry 700-pound payloads, however.

It is in POBAL's unique combination of mission duration, range, and speed that its characteristics differ most radically from any drone. Although immediate goals for current drone development are increased endurance, high altitude capability, and slow speed, the fixed-wing drone aircraft is basically a high speed, long range, short duration vehicle compared to POBAL. The phenomenal 36-hour endurance recently reported for an advanced experimental drone is twice the endurance of its nearest competitor; conventional drones typically have durations of a few minutes. In contrast, the POBAL mission endurance is one week or more with fuel cell power and twenty days to several months with solar cells.

Range, for most drones, is measured in hundreds of miles, whereas POBAL is specifically designed to remain within a very few mile radius of a designated location, while it floats above 60,000 feet throughout its prolonged mission. A drone helicopter obviously would have a similar hovering capability, but its ceiling altitude would be very low, and its duration presumably would be limited by a much greater power requirement than POBAL.

There are at least two other practical considerations. Unlike drones, POBAL is limited to operation during the season of minimum high-altitude winds. It has the great advantage, on the other hand, that balloon payloads can be configured in almost any shape and volume and need not conform to the stringent design specifications required for integration with a drone aircraft.

7-4. REQUIRED DEVELOPMENT

There are several areas requiring major developmental work in order to achieve an operational POBAL system. These are as follows:

(a) Development of a light-weight power supply system

(b) Development of a shaped superpressure balloon

(c) Meteorological studies

(d) Development of altitude-changing capability

(e) Development of navigational equipment.

The two areas requiring the most immediate effort are the development of a suitable power supply and the design of the balloon.

7-4.1 Power Systems

To date, the primary emphasis has been on power requirements. Several studies have been made which indicate that the most likely candidate power sources

with a power output of 1.5 kW. It weighs 70 pounds. The weight of the solar cells alone is only 22 pounds and is comparable to the weight of CdS.

We would like to use an undirected array. The balloon surface would be the supporting structure. A directed array would be difficult to launch and control, and its greater complexity increases the probability of malfunction. However, the undirected array presents formidable structural problems and higher cost due to the considerably larger number of cells needed for the array.

7-4.2 Shaped Balloon

Let us now consider the choice of aerodynamically shaped or spherical balloon. The shaped balloon has an attractive coefficient of drag (assumed C_D = 0.07), but the large, lightweight one we require would be difficult to build and launch. The spherical balloon is relatively easy to fabricate and launch, but its C_D is high in comparison (C_D = 0.19); a large power source would be necessary to provide stationkeeping capability.

A comparison of several systems with 15-knot and 20-knot true air speed capability for seven days is shown in Figures 7-6 and 7-7. A spherical balloon is feasible at 15-knot capability, and when meteorological constraints allow its use, this type of balloon should be used. Preliminary studies indicate, however, that far more often a capability of 20 knots will be required, and then one must go to an aerodynamically shaped balloon system.

VELOCITY - 15 KNOTS

DURATION - 7 DAYS

SYSTEM	SHP	POWER WT	TOTAL WT
Round; AgZn+CdS S.C.	5.2	2,930	3,650
Shaped; AgZn+CdS S.C.	1.2	1,010	1,574
Shaped; H_2-O_2 F.C.	.8	375	960

S.C. - Solar Cell

F.C. - Fueld Cell

Figure 7-6. System Parameters: 15-Knot, 7-Day

Duration is another criterion that can change the system design. For very long durations (30 days and up), the only feasible power source is solar cells. For durations up to about 20 days, a fuel cell system is better due to its lighter weight. (See Figures 7-8 and 7-9).

for a high altitude, long duration, free powered balloon are an H_2O_2 fuel cell, a solar cell-secondary battery combination, or possibly a turbine engine modified to work at altitude with the proper amount of thrust.

A computer program was written to determine the feasibility and system requirements for a spherical, superpressure balloon powered by solar cells and AgZn secondary batteries. This program considers power requirements, battery capabilities, solar cell capabilities, lift, system weight capabilities, and propeller characteristics and then designs the smallest balloon system consistent with these inputs. Initially, the cadmium sulfide cell seemed a likely candidate due to its very light weight and low cost per cell, and the first program was run using a CdS array. Subsequently, we realized that silicon cells must also be investigated and the program was modified and run for silicon cells. For both cell types we assumed the output to be a cosine function of the angle of incidence.

Figure 7-5 shows a generalized flow diagram of the spherical balloon-solar cell program. With elimination of the daylight loop, it is the flow diagram for an aerodynamically shaped balloon-fuel cell program which was also developed. These programs, consistent with the state of the art, considered the use of solar cells, batteries, and fuel cells which have already been developed. Availability is not assured, however, for the CdS cells. At present they are not in production in the United States, and very limited work is being done in Europe. The existing CdS cells have degradation problems, low efficiency (about 2 to 4 percent), and very expensive interconnectors. These characteristics negate many advantages of CdS cells over silicon.

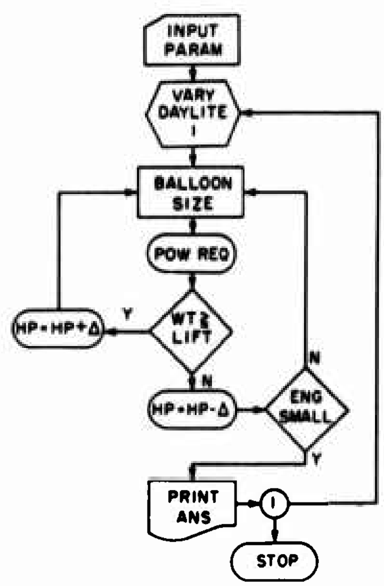

Figure 7-5. Computer Program Flow Diagram

The computer programs indicated that a useful power system will require an output in the range of 3 to 5 kW, or 2 to 10 shaft hp. If solar cells are used, it will probably be necessary to use silicon cells due to availability. They are more efficient than CdS cells, but they are very expensive and somewhat heavier for the same power output ($700, 000/kW). The most advanced silicon solar array to date is the flexible, rolled-up solar array (FRUSA), developed by the USAF Aero-Propulsion Laboratory, Wright-Patterson AFB, Ohio. This is a directional array

7-4.3 Meteorological

The eventual POBAL system will be limited in its applications because it depends upon the winds for its capabilities. Obviously, if wind speeds are stronger than the velocity capabilities of the system, it will not be able to stationkeep. In order to determine if a powered balloon is feasible for a particular operation, one must know the location, altitude, tolerances for both, duration required, and the time of year. From this information one would derive a climatology for the area. G. Nolan of AFCRL has done a great deal of work in this area. At present Mr. Nolan feels the most helpful charts for POBAL would be similar to the one shown for Las Vegas, Nevada in Figure 7-10. This chart shows the frequency of

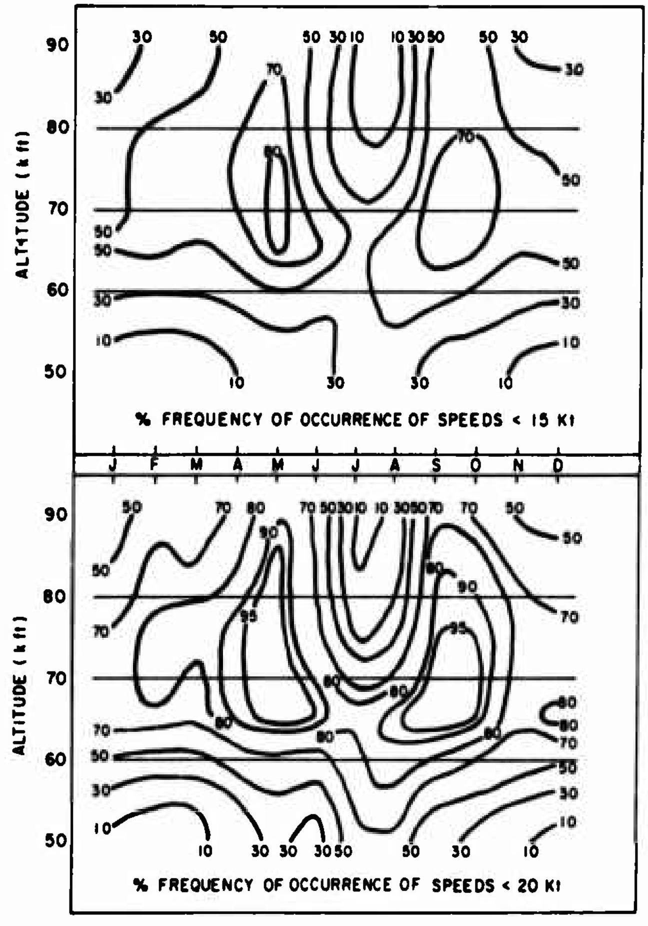

Figure 7-10. Wind Frequency, Las Vegas, Nevada

VELOCITY - 20 KNOTS

DURATION - 7 DAYS

System	Shp	Power Wt	Total Wt
Round: AgZn+CdS S.C.	18.8	9,413	10,600
Shaped: AgZn+CdS S.C.	2.6	1,590	2,360
Shaped: AgZn+Si S.C.	2.6	1,530	2,240
Shaped: H_2-O_2 F.C.	1.6	495	1,100

S.C. - Solar Cell

F.C. - Fuel Cell

Figure 7-7. System Parameters: 20-Knot, 7-Day

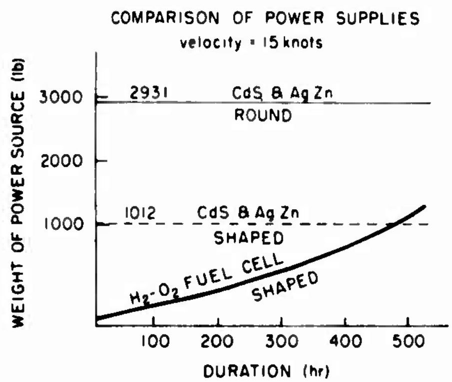

Figure 7-8. Comparison of Power Supplies: V = 15 Knots

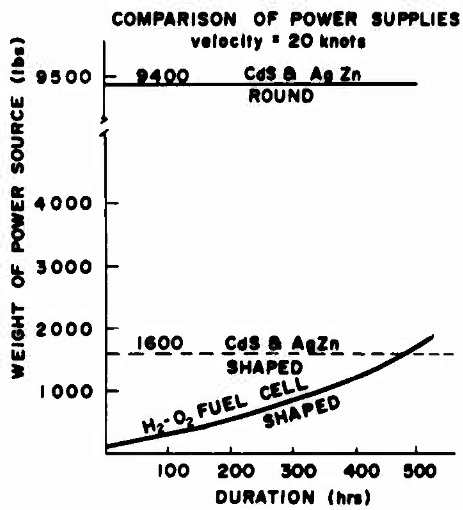

Figure 7-9. Comparison of Power Supplies: V = 20 Knots

The breakeven point is defined by the specific fuel consumption (SFC) and tank weight of the fuel cell system.

Some rules of thumb to use with primary H_2O_2 **fuel cells are:**

Weight of Reactants	.8 lb/kW-hr
Cryogenic Tankage	1/2 Weight of Reactants
Cell Hardware	30 lb/kW

There are several other types of power supply systems which we are investigating for possible use in this system. These include turbojet and shaft, nuclear power, laser beamed power and the Stirling (closed cycle) engine.

The Omega system is configured to provide all weather day-night capability. Although it is a hyperbolic system as is Loran, all of the transmitting stations are time synchronized so that it is not necessary to use a given pair of stations as with Loran. The signals are not only time synchronized, but are also phase locked to a common time standard. Omega suits the requirements for a dependable long-range navigation system better than any other system in operation. It has been in limited operational status since the spring of 1966, and four stations are currently on the air, although not transmitting full power. The eventual complete network of eight stations will provide full global coverage with a choice of stations for all areas. Completion is scheduled for 1975.

To utilize the Omega system with CRL balloons, we are developing under contract a balloonborne Omega signal processor with the objectives shown in Figure 7-11. Figure 7-12 illustrates pictorially our use of Omega with a scientific balloon package including a signal processor, which is receiving Omega transmissions from North Dakota, Trinidad, and Hawaii. The retransmission of position information to a remote ground station and a mobile station is depicted by the high frequency telemetry link.

This is probably the navigation system which will be used for POBAL as well as for other AFCRL packages.

7-5. CONCLUSION

OMEGA SYSTEM

Area Coverage	Global
Time Coverage	Continuous
Frequency	10.2, 13.6, 11.33 KHz
No. of Stations	8
Radiated Power	10 to 15 Kilowatts
Fix Accuracy	1 NM Day 2 NM Nite
Signal Format	Time Sequenced CW
Geometry	Hyperbolic or Circular
Measurement Technique	Phase Difference

Figure 7-11. Omega Systems

Figure 7-13 is an artist's concept of one possible ultimate system. For propulsion it uses a stern mounted propeller and motor, powered by a solar cell array and batteries in this case. Possibly it will instead use a fuel cell for power. It is aerodynamically shaped to reduce the coefficient of drag to an acceptable figure. It will have a 20- to 25-knot capability at 60,000 feet to 70,000 feet, a useful payload of 200 pounds, and a duration of several weeks. It can be used for such varied missions as an intelligence platform; a communications, command and control relay; a sensor technology test platform; pollution control; crop resources and earth resources surveys.

winds below a velocity of 15 and 20 knots for different altitudes at different times of the year. With this knowledge one could confidently fly a system with a 20-knot capability at 70,000 feet in the spring and fall. This confidence would be enhanced if the system had an altitude control capability of ± 5000 feet. One could seek the most favorable winds to keep on station. Just as important as this information is the knowledge that a system at 85,000 feet in December and January would have little chance of success. In order to properly use the powered balloon concept, a climatology chart must be prepared for the specified area.

7-4.4 Altitude Changing

At present the two most promising methods for changing altitude are air ballast and propulsion-system pitch control. An air ballast system designed by Rand Corporation under USAF contract might be used. It is essentially a balloon within a balloon. This concept will be investigated further. The motor pitch control effect is limited by the thrust available and would allow only small changes in altitude (approximately 2000 feet).

7-4.5 Navigation Equipment

Finally, a navigation system is required. For the test flight, the radar at White Sands Missile Range will be used for tracking, but since radar will not always be available, an on-board tracking capability such as Omega will be required. An autopilot will also be designed for the system.

Since the early 1950's, the primary method for tracking free balloons has been the use of high frequency beacon triangulation utilizing radio bearings taken on signals transmitted from the balloonborne payload. In the mid 60's the need for better positioning was apparent, and work began on several devices for alternate methods of balloon navigation and tracking. In 1968 a miniaturized version of a balloonborne omnirange locating system was proven operational and demonstrated accuracy consistently better than five miles on several balloon flights from Chico, California and Wallops Island, Virginia. These flights proved a theory that only six preselected omnirange frequencies need be employed to provide adequate position coverage across the entire continential United States at altitudes above 60,000 feet.

The need still prevailed for accurate tracking over remote sparsely settled areas and wide ocean areas. A survey was conducted of other available radio navigation aids as possible candidates for use with balloon systems. Omega emerged as the candidate to meet all objectives. Unfortunately, Omega was a long way from being an operational system.

This work is several years from completion and operational status. The completed test in September of this year is only the first step. Next the system herein described will be built, based upon detailed study of the design requirements. The flight will determine which areas require additional work. A new system will be built and flown as the last step prior to operational status, if no major problems remain.

Acknowledgments

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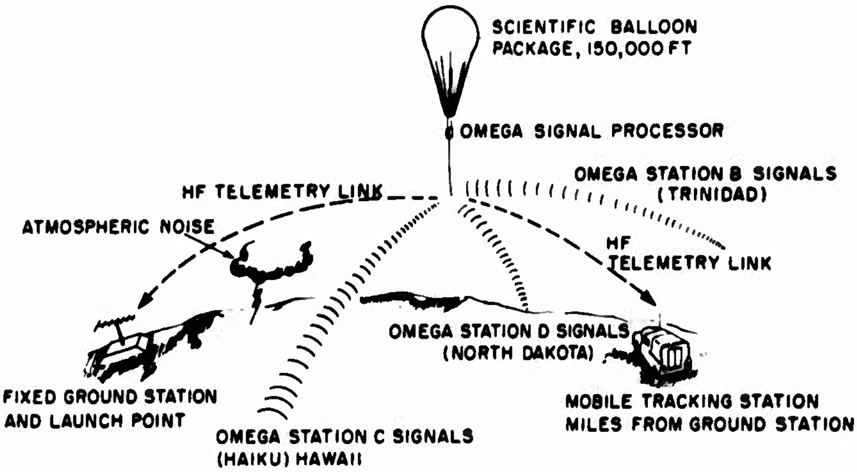

Figure 7-12. Balloon Positioning System

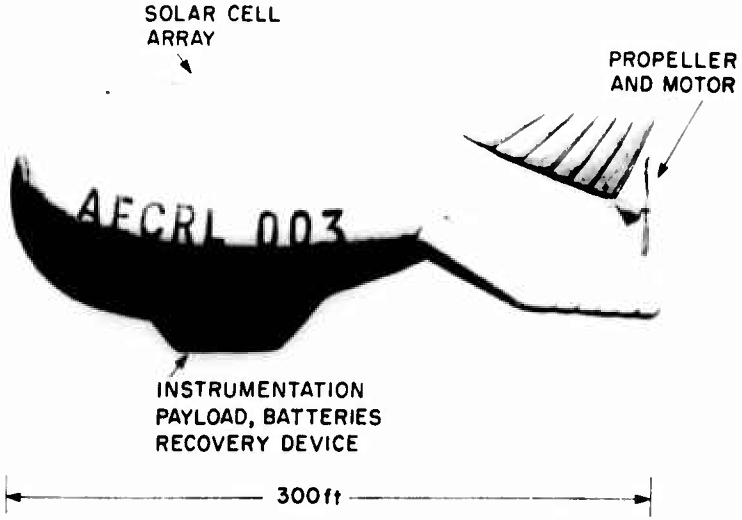

Figure 7-13. Sketch of Ultimate System